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Main characteristics of quartz-feldspar sands from the Khiva deposit, and the physico-chemical and technological fundamentals of obtaining an enriched concentrate

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ABSTRACT
This research presents studies on the beneficiation and application of quartz-feldspar sands from the "Khiva deposit" located in the Khorezm region of the Republic of Uzbekistan for the silicate industry. The composition of raw material samples was analysed using modern X-ray diffraction and IR spectroscopic methods. Based on the results, the quantitative mineralogical composition of the samples was determined using the BGMN/Profex Rietveld software package. According to the obtained data, the average chemical composition of the raw material (in wt.%) was determined as follows: SiO_2 – 86.06; Al_2O_3 – 2.64; Fe_2O_3 – 1.37; CaO – 1.37; MgO – 0.22; K_2O – 1.30; Na_2O – 1.85; TiO_2 – 0.04; SO_3 – 0.4, with a loss on ignition of 4.93. The beneficiation processes of the raw material were studied. Based on the specific characteristics of the composition, it was found appropriate in subsequent studies to apply combinations of beneficiation methods such as washing, gravity separation, classification, attrition scrubbing, electromagnetic separation, and flotation. As a result, it was determined that the SiO_2 content in the beneficiated concentrate increased from 86.06% to 97.07%, while Al_2O_3 decreased from 2.64% to 1.06%, and Fe_2O_3 from 1.37% to 0.05%.

Keywords: quartz, muscovite, concentrate, electron paramagnetic resonance (EPR), beneficiation, flotation, magnetic separation, electrostatic separation, X-ray diffraction analysis (XRD), infrared spectroscopic analysis (IR).

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Introduction

Despite the abundance of silica-based raw material reserves important for the production of silicate materials, only a limited number of deposits are suitable for the production of glass and glass products without the need for beneficiation [1]. The quality of glass and ceramic products largely depends on the chemical and mineralogical properties of the raw materials used [[2], [3], [4]]. It is well known that one of the main challenges in processing silicate materials is the high energy consumption during treatment.

Worldwide, the production of glass products is considered a vital sector of the national economy. The glass manufacturing industry is a major consumer of raw materials, energy, and labor resources, which in turn determines the development level of key economic sectors. Therefore, the efficiency of the glass industry is directly linked to the rational and economical use of these resources [[5], [6], [7]].

The Lower Amu Darya region of the Republic of Uzbekistan, including the Republic of Karakalpakstan and the Khorezm region, is considered rich in mineral raw materials. In particular, the Sultan Uvays deposit, located in the southern part of the Sultan Uvays mountain range and situated in the Qoraoʻzak, Beruniy, and Amudaryo districts, holds 2.6 million tons of feldspar reserves [8]. Additionally, the Zinelbulak talc-magnesite deposit, with total reserves of approximately 83.7 million tons, is primarily composed of talc and talc-magnesite [[9], [10], [11]], and serves as a major raw material base for silicate materials. Furthermore, quartz-feldspar sands from the "Yangiariq" and "Khiva" deposits, located in the Khorezm region, are also among these important sources [[8], [12]].

Among the raw materials used in the production of glass and glass products, natural high-silica rocks are of particular significance. Due to their distinctive physical-mechanical and technological properties, quartz sand is regarded as the primary raw material with wide industrial applications. The large-scale production of materials derived from this raw material has increased its demand across various industries. The growing need for silica-based raw materials and their products in the glass industry has led to an increasing demand for quartz concentrates, which are essential for the production of quartz glass [[1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]].

This article presents research on the beneficiation of quartz-feldspar sands from the "Khiva deposit" for their application in the silicate industry. The Khiva quartz-feldspar sand deposit is located near the surface, with depths ranging from 2.0–3.0 meters to as deep as 20.7 meters in some areas, and sand mound heights reaching 10–25 meters. The useful mineral at the deposit belongs to the group of aeolian sands from the Quaternary period and is situated in the form of horizontal layers. The sand grains are light yellow in color, finely dispersed, and compositionally classified as quartz sands. The balance reserves of the deposit are estimated at over 1,197 thousand cubic meters, or more than 2 million tons, under the A+B+C1 reserve categories [[12], [13]].

Experimental part

The suitability of feldspar-quartz sands from the Khiva deposit selected for the research was determined through quantitative, granulometric, chemical-mineralogical analyses, and beneficiation potential assessments. The quantitative characteristics of the raw materials were identified based on granulometric, chemical, and mineralogical composition analyses [[14], [15], [16]]. During the sample preparation for sand testing, the raw samples were first separated and placed on a square-shaped plywood surface and thoroughly mixed. An average sample was taken for quantitative analysis. The determination of the general granulometric composition of the selected samples was conducted in accordance with GOST 22552.0 standards. For this purpose, sieves No. 01 and 08 compliant with GOST 6613, a laboratory balance with an accuracy of 0.01 g according to GOST 24104, a mechanical shaker, and a drying oven equipped with a thermostat capable of maintaining a temperature of 105–110 °C were used. Initially, the samples were dried at 105–110 °C to constant mass. Then, three separate 100 g samples were prepared and subjected to sieving in a mechanical shaker for 10 minutes. Throughout the research process, the error margin of the obtained results was maintained within 0.1%.

Results and Discussion

The samples were taken from the surface and at depths of 3, 5, 7, and 10 meters in the area selected for quarrying. According to the provided data, samples 1–3 were collected from the surface layer, samples 4–5 from a depth of 3 meters, samples 6–7 from a depth of 7 meters, and samples 8–9 from a depth of 10 meters (Tab.1).

Table 1 - Chemical Composition of Feldspar-Quartz Sands from the Khiva Deposit

Sample	Oxide composition. weight per cent %									LOI. wt.%
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	SO_3	
1	85.98	4.69	1.08	2.04	0.33	1.57	1.07	0.04	0.09	3.11
2	85.98	4.68	1.05	2.04	0.32	1.57	1.10	0.05	0.08	3.13
3	85.97	4.67	1.06	2.05	0.32	1.58	1.09	0.04	0.09	3.12
4	86.01	4.68	1.13	1.99	0.33	1.48	1.03	0.06	0.08	3.21
5	86.12	4.60	1.13	1.96	0.34	1.47	1.01	0.06	0.08	3.23
6	86.22	4.59	1.13	1.95	0.33	1.49	1.01	0.08	0.08	3.12
7	86.29	4.56	1.11	1.95	0.34	1.50	1.01	0.08	0.08	3.08
8	86.63	4.41	0.98	2.09	0.28	1.46	1.07	0.05	0.12	2.91
9	86.63	4.41	0.98	2.09	0.28	1.46	1.07	0.05	0.12	2.91

Table 2 - Granulometric Analysis of Initial Raw Sand Samples Collected from the Deposit

Grain Size Classification. mm	Fraction Content by Sample. wt.%		
	K-1	K-2	K-3
Larger than 0.8 mm	1.1	1.0	1.3
0.8 mm to 0.4 mm	0.7	0.5	0.7
0.4 mm to 0.1 mm	87.4	87.8	86.6
Smaller than 0.1 mm	10.8	10.7	11.4
Total	100	100	100

Table 3 - Average chemical composition of feldspar-bearing quartz sands of the Khiva deposit

Sample	Oxide composition. weight percent %									LOI. wt.%
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	SO_3	
K-1	85.98	4.68	1.06	2.04	0.32	1.57	1.01	0.04	0.09	3.11
K-2	86.16	4.61	1.12	1.96	0.34	1.49	0.91	0.07	0.08	3.16
K-3	86.63	4.41	0.98	2.09	0.28	1.46	1.07	0.05	0.12	2.91
Average	86.32	4.56	1.05	2.02	0.31	1.51	1.06	0.05	0.10	3.02

When analyzing the chemical composition of these samples, it was found that samples 1–3 had almost identical compositions and were therefore combined and designated as the general sample K-1. Samples 4–7, taken from a depth of 3–7 meters, also had similar compositions and were designated as K-2, while samples 8–9 were identical and designated as K-3. The samples were dried to constant mass, prepared in equal weights, and sieved to determine the quantity of each fraction. Based on the results of the analyses, the determined granulometric analysis data are presented in Table 2 below.

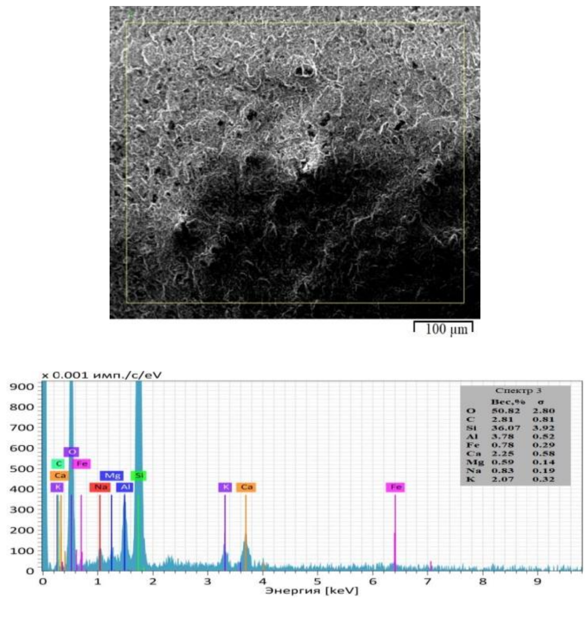

Figure 1 - SEM Image and EDS Spectrum of Feldspar-Quartz Sand from the Khiva Deposit

In all samples, the proportion of fractions smaller than 0.1 mm ranged from 10–12%, while fractions larger than +0.8 mm were present in amounts of 1.0–1.3%. It was also found that fractions with a particle size of 0.4–0.1 mm, accounting for 86.6–87.8% of the total, were predominantly coated with a light yellowish film on their surface.

The average results of the chemical analysis of the sands are presented in Table 3 below.

To verify the reliability of the chemical analysis results, elemental analysis of sample K-3 was conducted using a Bruker Quantax EDS (Energy-Dispersive X-ray Spectroscopy) system integrated into a SEM EVO MA 15 scanning electron microscope. The analysis results are presented in Figure 1. The obtained analytical results showed that the composition of the sample mainly consists of Si – 36.07 wt.%, along with minor amounts of elements characteristic of feldspar, such as K – 2.07 wt.%, Al – 3.78 wt.%, and Na – 0.83 wt.%. Additionally, small quantities of Ca – 2.25 wt.% and C – 2.81 wt.% were detected, indicating the presence of a minor amount of calcite mineral in the composition. To further determine the composition of these raw material samples, modern physico-chemical methods were applied, including X-ray diffraction (XRD) and infrared (IR) spectroscopic analyses (see Figure 2) [[17], [18], [19], [20], [21], [22], [23], [24]].

In the X-ray diffraction pattern, the strongest and most intense peaks were observed at d-spacings of 3.24 Å, 3.34 Å, and 4.25 Å, which correspond to α-quartz. Peaks at 3.03 Å, 2.57 Å, and 2.28 Å were attributed to feldspar; the 3.57 Å peak corresponds to hydromica, while the 3.18 Å peak is associated with biotite. Additionally, weaker intensity peaks at 10.51 Å, 7.10 Å, and 6.47 Å indicate the presence of chlorites, and peaks at 3.85 Å, 3.03 Å, 2.89 Å, and 2.28 Å correspond to calcite. Iron-bearing minerals such as hematite were mainly detected at 3.66 Å, 2.28 Å, and 1.45 Å.

Infrared spectroscopic (IR) analysis was also carried out on the same sample. According to the results, the presence of the –OH functional group was identified by stretching vibrations at 3368 cm^{-1}. No deformation vibrations were observed in this region, which indicates the absence of physically adsorbed water and suggests that the raw material is highly dehydrated.

The non-bridging Si–O bond was identified through stretching vibrations at 876 cm^{-1} and 1007 cm^{-1}, while bridging Si–O–Si bonds were confirmed by deformation vibrations at 459 cm^{-1}, 777 cm^{-1}, and 694 cm^{-1}. Bridging Si–O–Al bonds were observed through vibrations at 1434 cm^{-1}. Additionally, absorption bands at 591 cm^{-1} and 526 cm^{-1} correspond to sodium (Na) and potassium (K) feldspars, respectively. These findings confirm the presence of albite and microcline, as indicated in the XRD analysis.

The IR spectroscopic analysis theoretically supports and scientifically validates the results of the X-ray diffraction analysis.

Based on the preliminary studies conducted, it was determined that enrichment of these quartz sands is necessary for producing colorless and transparent glass enamel frits from this raw material. Therefore, in the subsequent stages of research, beneficiation processes were carried out on feldspar-bearing quartz sands from the Khiva deposit. According to X-ray diffraction (XRD) and infrared (IR) spectroscopic analyses, the Khiva quartz sand contains small amounts of chlorite, muscovite, microcline, limonite, hematite, and calcite. The physico-chemical properties of the mineral phases identified in the sample are summarized in Table 4.

The effects of gravity separation, classification, and flotation processes on increasing the silica (SiO_2) content of feldspar-bearing quartz sand samples from the Khiva deposit were studied under laboratory conditions (Table 5). The low efficiency of these beneficiation processes is due to the presence of 5–10 wt% brown, black, and light reddish iron-bearing mineral impurities, as well as the high content of iron oxides in the fine-dispersed clay fractions (50–65 wt%) and their presence on the surfaces of quartz grains (10–20%). In addition, according to mineralogical and petrographic characteristics, the samples contain, apart from iron oxides, other coloring agents—namely, titanium, chromium, cobalt, phosphorus, and manganese oxides—in amounts of 0.03–0.05 wt%.

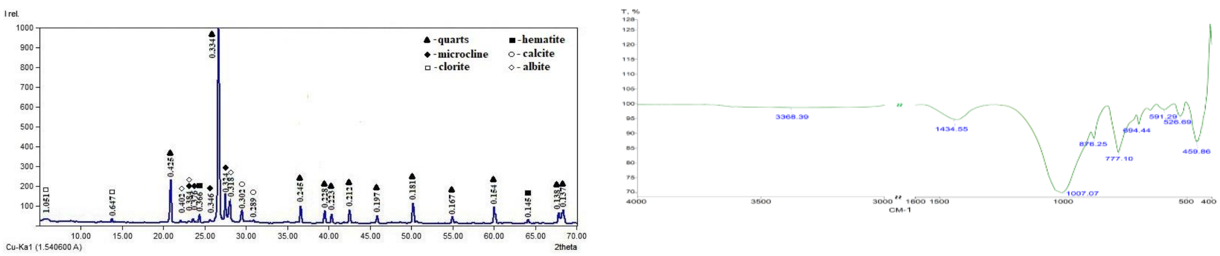

Figure 2 - X-ray Diffraction Pattern and IR Spectrum of the Feldspar-Quartz Sand Sample from the Khiva Deposit

Table 4 - Selected properties of accessory minerals in feldspar-bearing quartz sands of the Khiva deposit

Name of mineral	Density. g/cm³	Hardness (Mohs scale)	Refractive index	Magnetic behavior	Floatability
Muscovite	2.76-3.1	2.0-2.5	1.58-1.61	Non-magnetic	Floatable
Calcite	2.6-2.8	3.0-3.5	1.60-1.66	Non-magnetic	Not floatable
Chlorite	2.6-2.9	2.0-3.0	1.64-1.68	Non-magnetic	Floatable
Hematite	4.9-5.3	5.5-6.5	3.15-3.20	magnetic	Not floatable
Microcline	2.5-2.8	6.0-6.5	1.52-1.53	Non-magnetic	Not floatable

Table 5 - Changes in the content of major oxides during the beneficiation processes of samples taken from the Khiva deposit.

processes	Main oxide content change. wt.%			
	SiO_2	Al_2O_3	Fe_2O_3	others
Initial sample	86.32	4.56	1.05	8.33
gravity separation	88.86	3.12	1.02	7.00
classification	89.52	2.78	0.99	6.71
flotation	91.38	2.12	0.61	5.89

Based on the composition and the data provided above, it was determined that beneficiation of the sand samples using combinations of washing, gravity separation, classification, attrition scrubbing, separation in an electromagnetic field, and flotation methods is appropriate [23].

The beneficiation processes were mainly carried out using the following three methods:

Method 1 involved the following stages: washing, gravity separation, classification, and separation in an electromagnetic field. The sample obtained from this method (D-1) showed that the SiO_2 content increased by a factor of 1.04 compared to the initial raw material (D-0), while the contents of Al_2O_3 and Fe_2O_3 decreased by factors of 1.71 and 1.39, respectively. Method 2 differed from the first method by replacing gravity separation with flotation. The beneficiation stages followed this sequence: washing, flotation, classification, and electromagnetic separation. In the sample obtained by this method (D-2), the SiO_2 content increased by a factor of 1.05, while Al_2O_3 and Fe_2O_3 contents decreased by factors of 2.03 and 2.78, respectively.

Method 3, unlike the previous two, incorporated additional processes such as attrition scrubbing (mechanical rubbing). The stages were: washing, gravity separation, attrition scrubbing, classification, electromagnetic separation, and flotation. The resulting sample (D-3) showed an SiO_2 content increase by a factor of 1.13 compared to the initial sample (D-0), reaching 97.24 wt.%, which meets the requirements of GOST-22551-2019 for grade B-100-2. In comparison to the second method, Al_2O_3 content decreased by a factor of 1.69 to 1.32 wt.%, and Fe_2O_3 content decreased by a factor of 3.70 to 0.10 wt.%.

The quantities of major oxides identified during the analysis were evaluated based on the established normative documents and are presented in Table 6 below.

The photographic images of the samples separated after different stages are presented in Figure 3 below.

Table 6 - Chemical composition of quartz sands after beneficiation of samples taken from the Khiva deposit

Beneficiation method and sample	Main oxide content change. wt.%				Sand grade according to GOST 22551-2019
	SiO_2	Al_2O_3	Fe_2O_3	others	
Initial sample, D-0	86.32	4.56	1.05	8.33	Does not comply
First method, D-1	89.50	2.66	0.76	7.47	Does not comply
Second method, D-2	90.36	2.24	0.37	7.03	Does not comply
Third method, D-3	97.24	1.32	0.10	1.34	Complies with B-100-2

Figure 3 - Photographic images (magnified 100 times) of the initial and beneficiated samples of feldspar-containing quartz sand from the Khiva deposit: a) sample beneficiated by the first method; b) sample beneficiated by the second method; c) sample beneficiated by the third method.

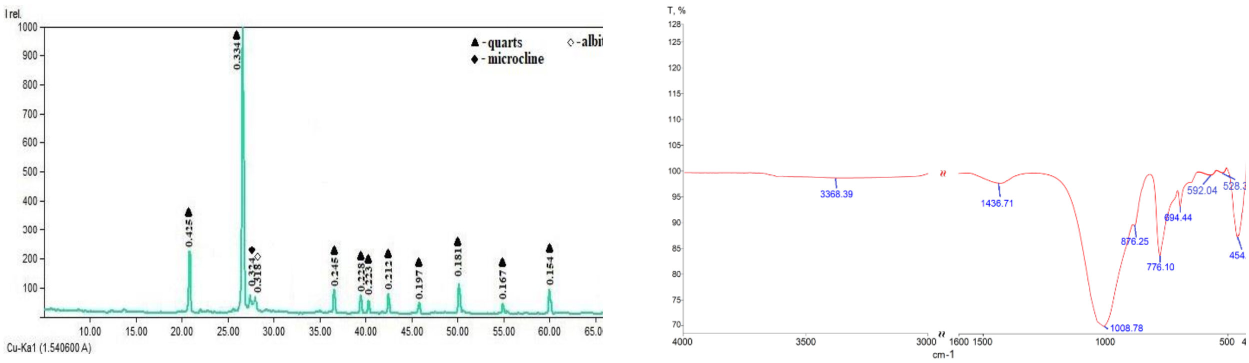

Figure 4 - X-ray diffractogram and IR spectrogram of the beneficiated feldspar-bearing quartz sand from the Khiva deposit

In this research, X-ray diffraction (XRD) and infrared (IR) spectroscopic analyses were conducted on the samples after the beneficiation of the quartz sands used as the object of study. The analysis results showed that, compared to the unprocessed samples (Figure 2), the intensity of the diffraction peaks of the minerals had decreased, and the peaks corresponding to iron-containing compounds such as hematite had completely disappeared (Figure 4).

Based on the results of numerous studies and the chemical-mineralogical composition of the Khiva feldspar-bearing quartz sand, a specific beneficiation technology with optimal technological parameters has been developed. According to the proposed technology, considering the easy washability of clayey materials in the composition, it was found that the additional use of a hydrocyclone unit is effective.

Conclusions

In this scientific study, the chemical, mineralogical, and granulometric composition as well as the beneficiation potential of feldspar-bearing quartz sands from the Khiva deposit were thoroughly investigated. Initial analyses revealed that the raw material primarily contains quartz, feldspar, calcite, chlorite, hematite, microcline, and other minerals, along with iron-bearing and clay-like impurities. These components limit the direct use of the sand in the glass industry.

During the study, the beneficiation processes were carried out using three main technological methods. The third method — which included washing, gravity separation, attrition scrubbing, classification, separation in an electromagnetic field, and flotation — was found to be the most effective. As a result of this method, the SiO_2 content in the beneficiated sample (D-3) increased to 97.24 wt.%, meeting the requirements of GOST 22551-2019 for the B-100-2 grade. Furthermore, the significant reduction in Al_2O_3 and Fe_2O_3 contents confirmed the improved suitability of the raw material for glass production.

Changes occurring during the beneficiation process were scientifically substantiated through X-ray diffraction and infrared spectroscopic analyses. A reduction — and in some cases, the complete removal — of hematite and other contaminant phases in the beneficiated sample was observed, further confirming the effectiveness of the beneficiation process.

Conflicts of interest. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Хива кенорнының кварц-дала шпатты құмдарының негізгі сипаттамалары және байытылған концентрат алудың физикалық, химиялық және технологиялық негіздері

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Қабылданды: *3 қыркүйек 2025*

ТҮЙІНДЕМЕ
Бұл зерттеу жұмысында Өзбекстан Республикасының Хорезм облысында орналасқан «Хива кені» кварц-дала шпатты құмдарын байытып, оларды силикат өнеркәсібінде қолдану бойынша зерттеулер баяндалған. Шикізат үлгілерінің құрамы заманауи рентгенографиялық және ИҚ-спектроскопиялық әдістермен зерттелді. Алынған нәтижелер негізінде BGMN/Profex Rietveld бағдарламалар жинағы арқылы үлгілердің минералогиялық сандық құрамы анықталды. Белгіленген мәліметтерге сәйкес, шикізаттың орташа құрамы массалық үлес түрінде келесідей болды: SiO_2 – 86,06%; Al_2O_3 – 2,64%; Fe_2O_3 – 1,37%; CaO – 1,37%; MgO – 0,22%; K_2O – 1,30%; Na_2O – 1,85%; TiO_2 – 0,04%; SO_3 – 0,4%, ал күйдірген кезде масса шығыны – 4,93% құрады. Шикізатты байыту процестері зерттелді. Құрамының ерекшеліктеріне сүйене отырып, келесі зерттеулерде байытудың – жуу, гравитациялық, классификация, үгіту арқылы жуу, электромагниттік өрісте сұрыптау, флотация әдістерінің комбинацияларын қолдану орынды деп танылды. Байытылған концентраттың құрамы бойынша SiO_2 мөлшері 86,06%-дан 97,07%-ға дейін артқаны, ал Al_2O_3 2,64%-дан 1,06%-ға, Fe_2O_3 1,37%-дан 0,05%-ға дейін азайғаны анықталды.

Түйін сөздер: кварц, мусковит, концентрат, электронды парамагниттік резонанс (ЭПР), байыту, флотация, магниттік сепарация, электрлік сепарация, рентгенографиялық талдау, ИҚ спектроскопиялық талдау.

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Основные характеристики кварц-полевошпатовых песков Хивинского месторождения и физико-химические и технологические основы получения обогащённого концентрата

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В данном исследовании изложены результаты изучения возможности обогащения кварц-полевошпатовых песков месторождения «Хива», расположенного в Хорезмской области Республики Узбекистан, с целью их применения в силикатной промышленности. Состав образцов сырья был исследован с использованием современных рентгенографических и ИК-спектроскопических методов анализа. На основании полученных данных, с помощью программного комплекса BGMN/Profex Rietveld был определён количественный минералогический состав образцов. Согласно установленным данным, средний химический состав сырья в массовых процентах составил: SiO_2 – 86,06; Al_2O_3 – 2,64; Fe_2O_3 – 1,37; CaO – 1,37; MgO – 0,22; K_2O – 1,30; Na_2O – 1,85; TiO_2 – 0,04; SO_3 – 0,4; потеря при прокаливании – 4,93%. Были изучены процессы обогащения исходного сырья. С учётом особенностей его состава, в дальнейших исследованиях целесообразным признано применение комбинированных методов обогащения, включающих промывку, гравитацию, классификацию, истирающую промывку, сортировку в электромагнитном поле и флотацию. В результате обогащения содержание SiO_2 увеличилось с 86,06% до 97,07%, содержание Al_2O_3 снизилось с 2,64% до 1,06%, а Fe_2O_3 – с 1,37% до 0,05%.

Ключевые слова: кварц, мусковит, концентрат, электронный парамагнитный резонанс (ЭПР), обогащение, флотация, магнитная сепарация, электрическая сепарация, рентгенографический анализ, ИК-спектроскопический анализ *(инфракрасная спектроскопия).*

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